

Figure 1. This **Three-Stage MMIC HEMT Amplifier** occupies a chip area with dimensions of 1.1 by 1.9 mm.

the upper part of Figure 2, the small-signal gain ( $S_{21}$ ), was found to be  $>10$  dB from 144 to 170 GHz, while input and output return losses ( $S_{11}$  and  $S_{22}$ ) are both approximately 10 dB at 165 GHz.

For the power measurements, the amplifier circuit was biased at a drain potential of 2.1 V, a drain current of 250 mA, and gate potential of 0 V (these biases were chosen to optimize the output power). As shown in the lower part of Figure 2, the output power ranged from a low of about 11.8 dBm ( $\approx 15$  mW) to a high of about 14 dBm ( $\approx 25$  mW). The peak power output of about 14 dBm was achieved at 150 GHz at an input power of 6.3 mW, yielding a large-signal gain of slightly less than 8 dBm.

*This work was done by Lorene Samoska of NASA's Jet Propulsion Laboratory, and Vesna Radisic, Catherine Ngo, Paul Janke, Ming Hu, and Miro Micovic of HRL Laboratories, LLC. Further information is contained in a TSP (see page 1). NPO-30127*

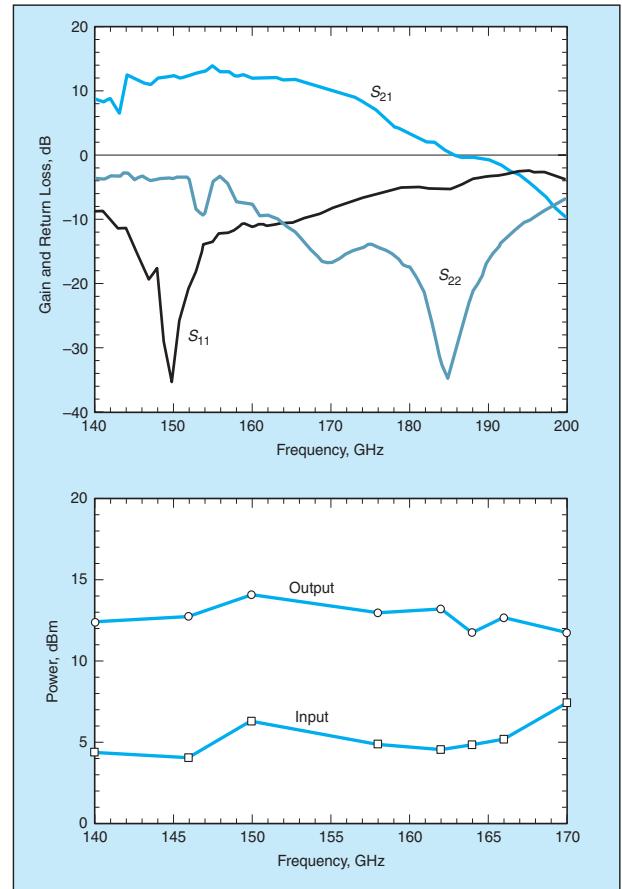


Figure 2. The **Small-Signal S Parameters and Power Output** of the amplifier were measured over its design frequency range.

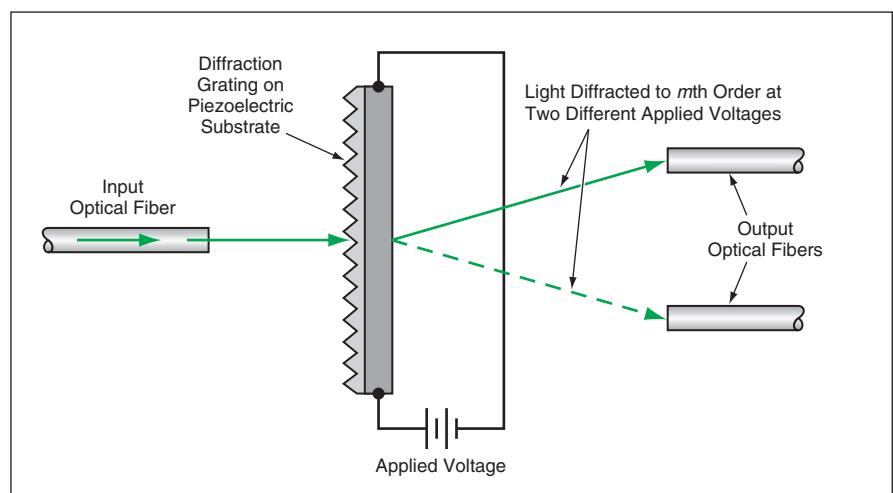
## Piezoelectric Diffraction-Based Optical Switches

Switching times can be short enough for demanding applications.

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Piezoelectric diffraction-based optoelectronic devices have been invented to satisfy requirements for switching signals quickly among alternative optical paths in optical communication networks. These devices are capable of operating with switching times as short as microseconds or even nanoseconds in some cases.

The basic principle of this invention can be illustrated with reference to a simple optical switch shown schematically in the figure. Light of wavelength  $\lambda$  is introduced via an input optical fiber. After emerging from the tip of the input optical fiber, the light passes through a uniform planar diffraction grating that is either made of a piezoelectric material or is made of a non-piezoelectric material bonded tightly to a piezoelectric substrate. A voltage can be applied to



The Period of the Diffraction Grating Is Varied between two values by switching between two values of voltage applied to the piezoelectric substrate, thereby switching between two different angles of  $m$ th-order diffraction. Output optical fibers are positioned to intercept the diffracted light at the two angles.

the piezoelectric member via electrodes at its ends to vary the spatial period of the grating. Two output optical fibers are positioned near the grating, opposite the input fiber.

The angle of diffraction of  $\lambda$ -wavelength light to any given order,  $m$ , depends upon the wavelength, the angle of incidence, and the spatial period of the grating. Hence, for a given fixed angle of incidence, one can change the angle of  $m$ th-order diffraction by varying applied voltage. The relative positions and orientations of the input fiber, the grating, and the output optical fibers are chosen in conjunction with the grating period so that (1) when no voltage or a given fixed voltage is applied, the  $m$ th-order-diffracted light of wavelength  $\lambda$  impinges on one of the output optical fibers and (2) when a different given fixed voltage is applied, the  $m$ th-order-diffracted light of wavelength  $\lambda$  impinges on the other out-

put optical fiber. Thus, by switching the applied voltage between the two given fixed values, one switches the light between the two output optical paths.

It is also possible to make the device described above perform the following additional functions:

- If only one output optical fiber is used to intercept  $m$ th-order-diffracted light and the input light includes multiple wavelengths, then the output wavelength can be selected by applying a corresponding voltage to the piezoelectric member.
- For given fixed values of the angle of incidence, diffraction angle, and wavelength, one can choose a discrete value of applied voltage to select a given diffraction order.
- For given fixed values of the diffraction angle and wavelength, it is possible to vary the applied voltage to switch among different angles of incidence in

order to select among different inputs.

Of course, it is possible to design devices more complex than that illustrated in the figure. For example, a device could contain crossed piezoelectric gratings for switching between an input optical fiber and multiple output optical fibers terminated in a planar array. Other examples could include devices that produce more complex switching effects by means of curved gratings, chirped gratings, and/or multiple piezoelectric actuators that bend or twist grating surfaces or that vary grating spatial periods along multiple coordinate axes.

*This work was done by Stevan Spremo, Peter Fuhr, and John Schipper of Ames Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-14638.*